USE OF TOOTHED ANCHOR CHANNELS FOR FIXING PRECAST CONCRETE CLADDING PANELS IN SEISMIC REGIONS

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SUMMARY

Investigations following past earthquakes have shown that the performance of Precast Concrete Claddings (PCC) is generally limited by the capacity and flexibility of the connections to the main structure. Failure of PCC connections can cause life threatening hazards due to falling objects and significant economic losses due to the time and cost to repair.

The investigations revealed that the typical causes of the PCC connection failures were primarily due to a combination of design and installation issues. Some designs utilised non-flexible connections, which were incompatible with the movement requirements of inter-story drift. In other scenarios, the installation methods did not allow for construction tolerances, which caused a different load distribution then the design assumption.

Toothed anchor channels are pre-engineered solutions that provide capacities based on internationally approved methods of assessment in seismic regions whilst providing adjustability. They are available in different materials for various levels of corrosion resistance and are easy to install. In addition to speeding up construction, the adjustability helps to avoid any misalignment that might result in un-expected load distribution during a seismic event.

In comparison to post-installed anchors, the installation of anchor channels does not require the use of electric tools and does not create silica dust. In contrast to weld plates anchor channels do not require on-site welding. Thus, anchor channels meet the requirements of modern jobsites for a quick and safe installation.

INTRODUCTION

The PCC panels are a popular type of building façade incorporating individual concrete panels which are fixed back to the superstructure and separated from each other with joints filled with a waterproof filler and sealant. PCC facades have been commonly used in a variety of building types in New Zealand and the rest of the world since the 1960’s and are desirable as they offer a variety of styles and finishes, provide long-term durability, require low maintenance and allow a fast speed of erection when compared to in-situ concrete.

The initial stage in the design of a PCC project is to coordinate the panel joint locations with the supporting elements of the superstructure whilst ensuring the weight and dimensions of the panels are economical for transport and installation. The next stage is to develop the concept of the connection system that secures the panels to the main structure (PCI Designer’s
The panels are typically designed as non-structural components and are sensitive to both storey drift and seismic floor accelerations. The connection system needs to ensure the inertial force of the PCC panels are transmitted back to the main structure whilst accommodating the estimated displacements and ensuring the panels are structurally isolated such that no other forces from the building itself pass through the panel (Pantoli et al. 2016).

Investigations following past earthquakes have shown that failures in non-structural components pose a significant risk to human life and can cause significant economic losses and disruption due to building repair downtime. While the majority of the PCC facades during the 2011 Christchurch earthquake exhibited little to no damage, several failures still occurred due to inadequate detailing and installation errors of the panel connections (Baird et al. 2012a). As the failures of PCC panels are predominately due to failure of the connections, a sound understanding of the design and detailing of the connections as well as the installation procedures of PCC panels is essential to ensure the façade performs as expected during a seismic event.

This paper summarises the typical design approach of PCC panel connections, introduces toothed anchor channels as a fixing method for the connections and provides a comparison of the toothed anchor channel solution with the fixing methods currently used in New Zealand.

TYPICAL SEISMIC CONNECTION DETAILS OF PCC PANELS

Isolating PCC panels from the supporting building structure is a common approach when seismic events need to be considered in the design. In order to minimise the interaction between the panel and the structure, the connection system needs to resist both gravity and out-of-plane loads whilst accommodating displacements due to in-plane storey drifts. When the connections allow for the introduced displacement the PCC panels can be designed as isolated non-structural elements. In cases where the connection does not allow for the displacements experienced in extreme seismic events the additional stiffness of PCC panels can lead to a change in load distribution which can cause failure of the PCC or load bearing elements.

Recent studies have shown that PCC panels can provide a substantial increase to the overall stiffness of a structure if the PCC and its connection is designed to work in conjunction with the main structure (Baird et al. 2012b). Different types of energy dissipative connections have been developed during recent years to utilise the additional stiffness provided by the PCC panels and to improve the seismic performance of the structures however these connections are not discussed in this paper.

Typical isolated PCC panel connections consists of two bearing connection at the bottom of the panel and two movement connections at the top of panel. The bottom bearing connections are designed to transfer loads in all three directions while the top movement connections are detailed to only resist out-of-plane loads whilst allowing in-plane lateral displacement with minimal resistance during an earthquake as shown in figure 1.
The bearing connections generally consist of a stiff bracket that connects the back of the PCC panel to the top of the slab. Other options for bearing connections exist that allow fixing to the front of a column or to the edge of the slab however, these types of brackets are less favoured as the panel hinders access to the brackets making installation more difficult. The movement connections are generally detailed using either a sliding bracket or a flexing rod. The sliding bracket utilises a horizontally slotted hole to accommodate the in-plane movement while the flexing rod method provides the required displacement via bending of a slender rod. Figure 2 illustrates typical examples of these connection types.

Investigations into past failures show that the movement connections are the most susceptible to installation errors. The errors in installation can lead to a different load distribution then the original design resulting in the failure of the connection. A typical example is the misuse of the horizontally slotted hole in the sliding connection as a means of providing tolerance in the position of the fixing. When the bolt is not installed in the centre of the slotted hole, the movement allowance assumed in the design can potentially be reduced which can lead to an overload as the connection will exhibit lateral forces that were not originally allowed for in the design. The flexing rod connection has also been prone to installation errors in the past where the connecting bracket was installed closer to the panel than detailed in the design. In doing so, the free length of the rod is reduced resulting in a stiffer connection thus attracting larger loads then the original design which can lead to failure of the connection (Del Monte et al. 2018).
Once the load distribution has been determined, each bracket can be individually designed. Care must be taken to ensure all reactions caused by any eccentricity of the applied load are considered in the design (Baird 2018). It is also essential to ensure all connections are limited by a ductile failure mode. As failure of the fixing or the panel is generally a brittle failure, ductility can be achieved by designing the connector body to yield before the panel or fixings fail (Figure 3).

The larger loads resisted by the bearing connections generally make the design of these connections more challenging, especially when the panel or slab is relatively thin as this can limit the choice of fixing options. The capacity of the fixing is typically influenced by the distance to the concrete edge, thus additional fixing capacity can generally be obtained by increasing its edge distance. For the connection into the slab, a larger edge distance also reduces the resultant gravity loads in the fixing due to the increased lever arm however the connector body becomes more slender which may require an increase in thickness. The optimal design will adopt the edge distance which achieves a ductile failure with the smallest connector body thickness.

![Figure 3- Possible failures of PCC panel connection](image)

**CURRENT FIXING SOLUTIONS**

Despite sufficient ductile design of PCC panel connections, observations of the aftermath of the Christchurch earthquakes revealed that installation errors or insufficient tolerance can result in a brittle failure in the fixing creating a high risk of complete detachment of the cladding (Baird et al. 2013). It is important that the designer fully understands the mechanism of the chosen anchoring product including the potential risks associated with the installation and the consequences installation errors may have on the design. Anchor systems can be divided in cast-in place systems and post-installed systems. Figure 4 gives an overview over the different types of systems that are currently available.
Cast-in place systems like threaded inserts, also called ferrules, are limited in their application as they do not allow for building tolerances. Weld plates allow for limited tolerances but do not meet the demand of modern construction sites as they require on site welding causing safety issues and slowing down the overall building process. Post installed systems can accommodate building tolerances but their installation is slow in comparison to threaded cast-in place solutions.

While cast-in place systems normally depend on headed anchors to transfer the load in the concrete, most post-installed anchor systems rely on friction or adhesive bond. Post installed anchors used in cracked concrete under seismic conditions need to be explicitly qualified to satisfy the requirement of NZS 3101 clause 17.5.5. If an anchor is positioned in a concrete tension zone the concrete must be assumed as cracked. If cracks open near or even through the anchor location they will negatively affect the ability to transfer stresses from the anchor into the surrounding concrete (Eligehausen et. al. 2006).

Besides the negative impact of cracking on the capacity of post installed anchors, bonded anchor systems will also show a big impact on capacity when installed improperly. Studies in different parts of the world have shown that a proper cleaning of the bore hole like described in the manufacturer’s installation instruction is often not done leading to a significant decrease in capacity of bonded anchors. In catastrophic failures of post installed anchors like the “Big dig tunnel collapse” with one fatality in Boston, U.S. in 2006 or the Sasogo tunnel accident in Japan with 9 fatalities in 2012, the identified issues always included improper anchor installation as well as insufficient inspection (Boomkamp 2017).
TOOTHED ANCHOR CHANNEL SOLUTION

Anchor channels, either hot-rolled of cold-formed C-shaped channel profiles with at least two I-shaped anchors welded to the back, are a safe and efficient method of anchoring tension and shear loads into both cracked and un-cracked concrete. The anchor channels are installed before the concrete is poured, the installation is easy and leaves little room for installation errors that could cause a reduction of the system capacity. Loads are introduced by channel bolts, also called T-bolts, which are inserted into the channel slot and transfer the loads safely into the channel through the channel lips. The channel bolts provide the adjustability required to compensate for construction tolerances.

In Europe the qualification of anchor channels is regulated through the European Assessment Document (EAD) 330008-02-0601 (EAD 2016). The design of anchor channels has to comply with the standard EN 1992-4. In the United States of America with AC 232 - Acceptance Criteria for anchor channels in Concrete (AC 232 2016) by the Evaluation Service of the International Code Council (ICC-ES), and in Australia by AS 5216 - Design of post-installed and cast-in fastenings for use in concrete (AS 5216 2018). All three documents promote the same design method for tension loads as well as shear loads perpendicular to the longitudinal axes of the anchor channel. Since February 2016, AC232 also covers loads in the longitudinal axis of the anchor channel and includes the design for seismic conditions allowing their use in all seismic design categories (A – F) provided the channels are capable of providing resistance in all three axes. A common approach to achieve a load capacity in the longitudinal direction is to use so called toothed anchor channels (Figure 5) (Boomkamp 2017).

![Figure 5-Toothed anchor channels and toothed T-bolts](image)

Toothed Anchor channels are an ideal solution for fixing into concrete when adjustability is required such as in the case for façade connections including the connections on PCC Panels. When combined with brackets that utilise slotted holes, serrated pads and serrated washers, adjustability in all directions can be achieved (figure 6).
Their simple, repetitious and quick installation procedure meet the safety, tolerance and time demands of the modern construction industry and as a result has received a strong uptake in international markets over the last few decades. Their use allows the full benefit of a PCC panel façade system to be realised through reduced crane and labour costs during installation.

The in-built adjustability also reduces the risk of installation errors such as the misuse of the slotted hole in sliding connections or reducing the rod length in flexing rod connections allowing the design to perform as anticipated, ensuring ductility in a seismic event. Replacement of deformed brackets or rods after an earthquake is simple when they are fixed with toothed anchor channels.

Anchor channels and T-bolts are available in Hot Dip Galvanized and Stainless Steel materials for increased durability performance if required. As they are pre-engineered products that are easy to install, they are less susceptible to human factors allowing them to perform as expected throughout the life of the structure. By following the manufactures guidelines for design and installation, all possible failure modes associated with both the steel and concrete are considered allowing the behaviour to be predicted correctly. With 17 failure modes and numerous bolt locations along the channel, performing hand calculations of anchor channels connections becomes quite complex and time consuming. It is recommend to utilise any calculation software that is provided by the manufacture to ensure the design is conducted in accordance with the relevant acceptance criteria such as the EAD or AC232.

For conditions where the factored tensile and shear loads exceed the concrete breakout strength and concrete failure modes govern the connection design, additional capacity can be achieved through the use of supplementary reinforcement by following the requirements of NZS 3101 (2006). Figure 7 shows an example layout of supplementary reinforcement for an anchor channel positioned on top of a slab with an applied shear force acting towards the edge. The same principle can be applied for other configurations. The size, quantity and spacing of the supplementary reinforcement should be chosen such that the anchored capacity of the reinforcement on both sides of the crack pattern satisfy the factored applied loads. The chosen bar size may be limited by the relevant approval of the product, for example the ICC approval requires a maximum diameter of 16mm for supplementary reinforcement.
CONCLUSION

Precast concrete cladding is an efficient and desirable façade system and will continue to be selected as the system of choice in future developments. The vast portion of undamaged panels during the Christchurch earthquakes demonstrate that the system can perform safely during seismic events provided the installation of the panel and the associated connections are conducted correctly. The use of toothed anchor channels as part of the connection system can not only increase the speed of installation but also substantially reduce the risk of installation errors due to their simple installation and in-built allowance for construction tolerance.

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